Bringing the Universe to the World: Lessons Learned from a Massive Open Online Class on Astronomy

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This paper presents the results of a massive open online class (MOOC) on astronomy called *Astronomy: Exploring Time and Space*. The class was hosted by the web platform Coursera and ran for six weeks from February to May 2015. Coverage was designed to emphasise topics in astronomy where there has been rapid research progress, including large telescopes, exploration of the Solar System, the discovery of exoplanets, exotic end states of stars, and the frontiers of cosmology. The core content was nearly eighteen hours of video lectures, assessed by thirteen video lecture quizzes, three peer review writing assignments, and two online activities. Information on demographics and on the goals and motivations of the learners was gathered using standard Coursera entry and exit surveys and an external Science Literacy survey. A total of 25 379 people registered for the course, and most of them did not complete any assignments. About two-thirds of the 14 900 learners who opened the course lived outside the United States, distributed across 151 different countries. Out of 4275 participants who completed one or more assignments, 1607 passed the course, and a majority did so with a grade of 80% or higher. Those who completed the course were generally very satisfied with their experience and felt it met their learning goals. The people with the highest chance of completing the course tended to be in the range 40 to 60 years old, had a college education, and were either retired or working in professional fields. The strongest predictors of passing the course were to have completed the first written assignment or the first online activity.

Introduction

Five years after they burst onto the educational scene, the jury is still out on massive open online classes (MOOCs). The number of MOOCs has grown dramatically to over 4000, and the number of learners is more than 35 million (Shah, 2015). A MOOC is a university-level course that's offered completely online with no prerequisites, usually free, though often learners pay for a completion certificate. There are three main types of providers: for-profit companies like Coursera[1] partner with universities and faculty to offer a wide range of subjects typical of a Liberal Arts curriculum; non-profit companies like edX[2] operate in a similar way and the smaller companies like Udemy[3] offer vocational courses and courses addressing professional development, with revenues shared between the company and individual instructors.

There is tension between the commercial and educational motivations of the MOOC providers (Ong & Grigoryan, 2015). None of these providers charge tuition fees in the way that major universities do, but their annual revenues are nearly $2 billion and that is expected to grow to over $8 billion by 2020 (Shah, 2015). MOOCs are here to stay.

Despite this strong growth, the debate over the efficacy of MOOCs and their role in the educational landscape continues unabated (Gammage et al., 2015; Hollands & Tirthali, 2014; MacAndrew & Scanlon, 2013). The benefit of free exposure to faculty expertise from major world universities is mitigated by the generally low completion rates of MOOCs, in the range of 6–10% (Khalil & Ebner, 2014). However, it is unrealistic to expect very high completion rates in a free-choice learning situation, with adult learners who have to juggle families and jobs and who are not as invested in the educational experience in terms of paying for tuition and receiving college credit. Many people clearly use the MOOC marketplace to browse options or sample an interesting subject without making a real commitment. Modular MOOCs still allow a lot of aggregate consumption of content and learning, even for those who are not completing the course. Moreover, a clear majority of those who do complete MOOCs report educational benefits and a majority also claim career benefits (Zhenghao et al., 2015).

A strong argument for the benefit of MOOCs is their role in democratising education, where people in lower income or developing countries can access world-class education with only Internet access (Dabbagh et al., 2015). That shine dims with the realisation that most MOOC learners already have degrees and jobs, and the majority come from developed counties (Hansen

& Reich, 2015; Ho et al., 2015). However, there remains a substantial minority of participants that includes those from countries with no well-developed higher education system and others where repressive governments try to suppress the free flow of information, so the idealistic goal of MOOCs is being realised, if on a fairly small scale. While the archetypal participant is a well-educated white male from a wealthy country, MOOCs are providing opportunities for advancement. Two years of data from Coursera show that people from developing countries more often report benefits from taking MOOCs, and people in those countries with low socioeconomic status and less education report the most benefits (Zhenghao et al. 2015).

MOOCs have been an important testbed for instructional strategies and pedagogy. Providers like Coursera offer a data-rich environment for researchers where learner privacy can be safeguarded while their behaviour can be analysed at the level of clicks on the website. One criticism is that MOOCs typically depend on video lectures and multiple choice quizzes, augmented by online discussions. For the most part, the pedagogy is transmissive and the learners are passive, similar to many traditional university learning environments. However, a growing body of research has demonstrated that the best learning gains come from methods that actively engage students and let them work with peers and also get direct feedback from instructors (Freeman et al., 2014; Waldrop, 2015). Typical online environments make this kind of instruction challenging, if not impossible. In addition, the current MOOC platforms do not support interactive modes of instruction or provide easy ways to incorporate external or third party tools. Few argue that online instruction rivals the best classroom experience, although some experts argue that virtual classes can be better than real ones (Oakley, 2015). On the plus side, though, they allow new tools and technologies to be tested readily on any MOOC platform, generating copious data and permitting a very rapid development cycle.

Each of these issues represents an opportunity for research and for learning how to improve online instruction. We started developing our course in 2012, and the goal was not a survey of astronomy topics that might be appropriate for a general education course, but coverage of the research topics, from comets to cosmology, where there is rapid progress. Our first offering was through course site Udemy, starting in February, 2013. That course is still running, and it has had over 36 000 people enrolled to date (Impey et al., 2015). We then augmented the video content by 50%, and started a second course on Coursera, which was the first offering by the University of Arizona after it joined their university consortium. That course ran for six weeks from February to May 2015 with over 25 000 enrolled learners, and is the subject of this paper. In the summer of 2015, we transitioned to Coursera's on-demand platform. A continuously enrolled course has been running on that platform since August 2015; it will be the subject of a future paper. Our goal in this paper is to detail the demographics and motivations of a typical MOOC audience, and identify indicators of engagement and predictors of course completion.

Course materials and pedagogy

Astronomy is a dynamic subject, with new research results reaching the level of the popular media almost daily. Particularly rapid progress is being made in the areas of exoplanets and cosmology. The course *Astronomy: Exploring Time and Space* was the first MOOC to be offered by the University of Arizona after it joined the Coursera consortium. The goal was to offer a survey of the subject with an emphasis on topics where advances in knowledge have been particularly rapid or profound. The major modules in the course were: the scientific method and the history of astronomy; the night sky; telescopes and the tools of astronomy; matter and radiation; the Solar System; extrasolar planets; the birth and death of stars; galaxies and the large scale structure of the Universe; cosmology and the big bang; and life in the Universe. The material often included research being done in the University of Arizona Department of Astronomy and Steward Observatory, one of the most prominent astronomy programmes in the world. Relative to an introductory astronomy textbook, the course gave particular emphasis to the method of science, big new telescopes, exoplanet detection and characterisation, tests of cosmological models, and the prospects of life in the Solar System and beyond.

As in most MOOCs, the core content was a series of video lectures. The ten high-level modules were divided into ten to twelve topics each, and the video segments were at the level of a topic, typically six to fifteen minutes long, with an average of ten minutes. Video was shot with HD resolution against a green screen so that background and graphics could be added later. Two camera angles were used for variety. The lead author acts as the instructor and is the talking head in all of the videos. The instructor did not read from a script; rather, he created a narrative from lecture slides created for this course. Images, animations and video clips were incorporated into the videos in the production phase. Video editing was done in Final Cut Pro X[4]. The goal for the video lectures was a natural style and a varied presentation so they would appeal to people accustomed to science shows on television and high quality web videos. The 109 video lectures total just under eighteen hours, which is at the high end for most MOOCs. No textbooks were used. Instead, the learners had access to a free electronic textbook and other online astronomy resources provided by the instructor at the "Teach Astronomy" website[5] (Impey et al., 2013).

It is always challenging to use pedagogy that engages learners in a disembodied online environment with thousands of participants. As in most MOOCs, *Astronomy: Exploring Time and Space* used multiple choice quizzes linked to the video lectures. A total of thirteen quizzes were used, each referring to about 75 minutes of video lecture. Learner engagement was increased with three writing assignments and two online activities. Each writing assignment was peer-reviewed using tools provided by Coursera that randomly assigned three reviewers to each piece of writing. The writing assignments were graded on a five-point scale using a rubric provided by the instructor that each reviewer used to score the work of their peers. The three topics for the 500-word writing assignments were: figures of merit for telescopes across the electromagnetic spectrum, the detection of exoplanets and their properties, and the exotic end states of stars. In addition, students completed two online activities. One was Galaxy Zoo (Lintott, 2008), a pioneering citizen science project that asks participants to classify a set of faint galaxies from the Sloan Digital Sky Survey[6]. The second online activity had the learners using the NASA MicroObservatory robotic telescope network[7] to take an image of an object in the sky, then write a brief report on the properties and the significance of the target chosen.

The course used other modes of engagement which did not affect the final grade or the ability to attain completion certificates. Coursera provides embedded discussion boards, and threads were created for each content module as well as for general course issues. Topics generated by the learners proliferated during the course, and included topics such as practical observing with small telescopes, UFOs, science and religion, and astronomy in the news. We could sort threads by activity level and popularity, and members of the instructional team tried to participate in every thread at least once. Live question and answer sessions were conducted using Google Hangouts every week of the course, and automatically archived and posted publicly on YouTube. The course had a Facebook page and a Twitter account, and the instructor maintained an active presence on social media, typically making three or four posts per week.

Learner demographics and motivations

Who takes MOOCs today? This simple question does not have a simple answer because free-choice learning can have many types of motivation (Falk and Dierking, 2002). Someone might take a course on programming or algorithms for advancement or for professional development, a course on photography to further a hobby, or a course on philosophy for general interest. We can assume that astronomy draws people because of curiosity or a fascination with the subject. This is probably a different motivation from that for the students at the University of Arizona, who take introductory astronomy as part of a General Education requirement. This course was offered over a six week period in the spring of 2015, and the instructor used his social media footprint to promote the course, reaching amateur astronomers and people who had read his popular books. Students started registering in early December 2014, and a stream of several hundred people a week registered over the two months that followed, with a spike in early February when Coursera started promoting the course in its online marketplace (Figure 1). By the time the course started 25 379 people had registered.

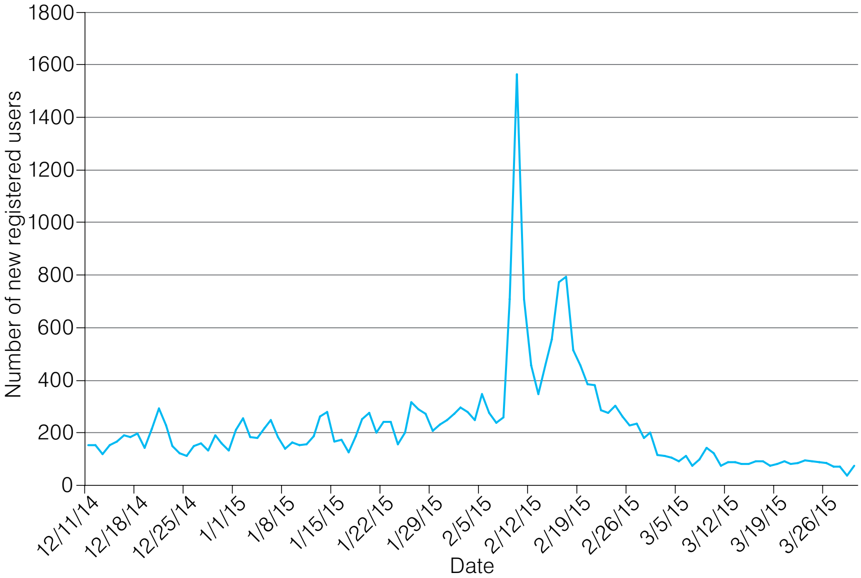

Figure 1. *Registration pattern for "Astronomy: Exploring Time and Space," a MOOC on Coursera that ran from February to May 2014. Many of those who pre-registered were amateur astronomers or teachers reached by the instructional team using social media.*

We gained valuable demographic information from two surveys carried out near the beginning of the course. Coursera gave their standard entry survey to a randomly selected group of 4657 registered learners and shared the anonymised data with us later. We then asked learners to complete a separate Science Literacy survey of our own design that gathered demographic information, as well as asking questions about basic science knowledge and attitudes towards issues of science and technology. We have used parts of this survey for over twenty-five years to measure science literacy in the undergraduate student population at the University of Arizona (Impey et al., 2011). The survey was voluntary, but was motivated by a small amount of credit towards course completion that did not significantly influence the final grade. A total of 2465 learners completed our external survey. Not surprisingly, respondents to the two surveys are skewed in favour of people who participated in the course, and people who passed the course. Out of the roughly 14 900 users who visited the course at least once, 11% graduated, whereas for the survey takers, the graduation rate was 33%. Full analysis of these two data sets is the subject of a separate paper.

As found in similar studies (Daly, 2014), those enrolled in the astronomy MOOC were substantially older than traditional students, with an average age of 36 and a median age group of 31–40 years old. The age distribution was flat except for a peak of people in their twenties (Figure 2). Learners' geographical locations were classified based on IP addresses. A third of those who visited the course at least once lived in the United States (34.8%). The next most common countries were India (8.2%), United Kingdom (4.7%), Canada (3.9%), China (3.8%), Brazil (3.1%) Spain (2.6%), Russia (2.4%), Australia (2.0%), and Germany (1.9%). A total of 151 countries were represented (Figure 3). In terms of occupations, the course attracted a diverse set of learners. As determined by our external survey the largest group was students (19%), followed by science and engineering professionals (11%), software and computer professionals (11%), and educators (9%). Surprisingly, the next largest category was unemployed people (8%). About equal were retirees and business managers at around 5% each (Figure 4). Consistent with other Coursera studies this was a highly educated cohort (Christensen et al., 2013). Only 16% did not have any level of college education, a third had bachelor's degrees and another third had advanced degrees (Figure 5). Many had had a substantial amount of previous college-level training in science. Only a

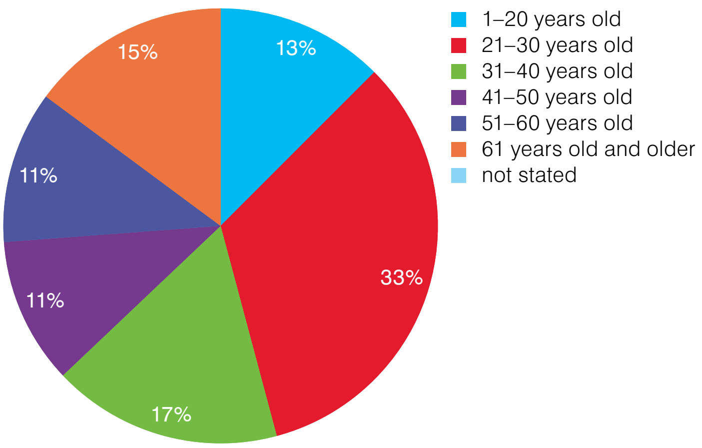

Figure 2. *Age distribution of the people registered for the MOOC from the sample of 2465 who took the external Science Literacy survey. The average age is 38 and the median is 55.*

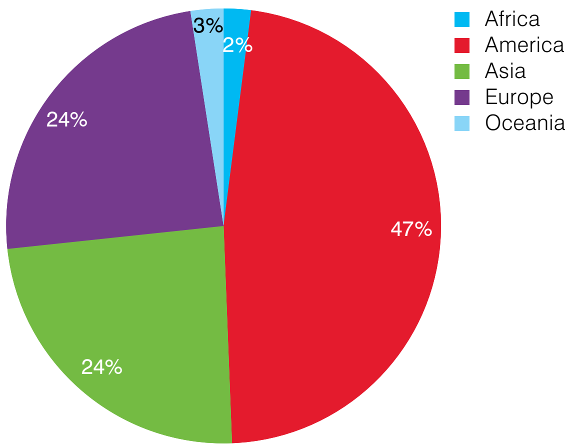

Figure 3. *Geographical distribution of the 14 900 MOOC participants who opened the course based on their IP addresses.*

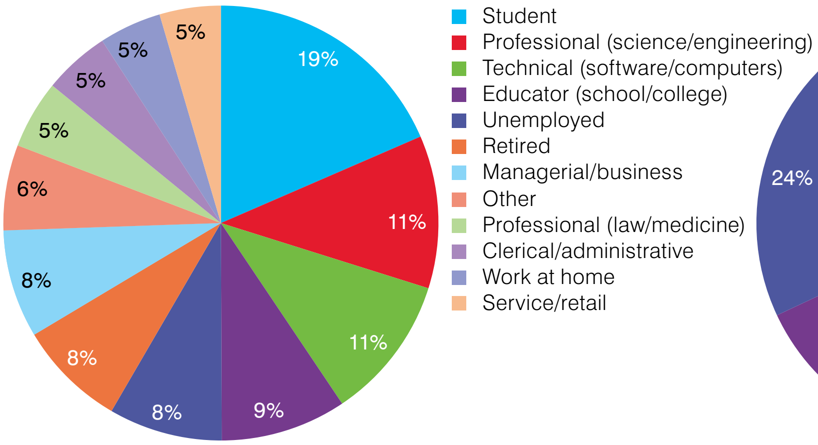

Figure 4. *Occupations of the sample of 2465 MOOC participants who took the external Science Literacy survey. A quarter worked in technical and professional fields.*

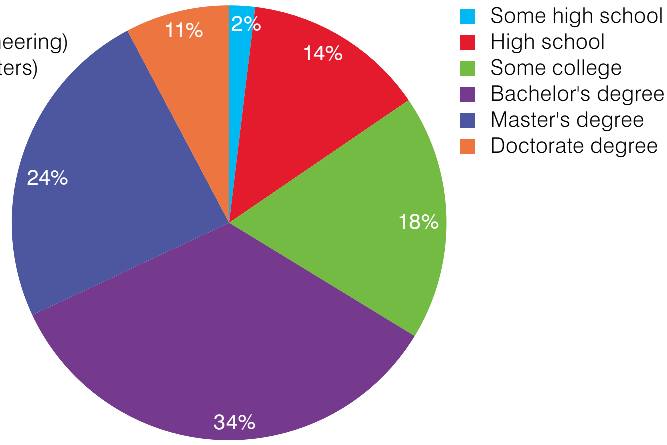

Figure 5. *Highest education level of the sample of 2465 MOOC participants who took the external Science Literacy survey. A third had bachelor's degrees and another third had advanced degrees.*

quarter had never taken any college science class, and a quarter had taken ten or more (Figure 6). In this context, a class represents a quarter-year or semester-long course for three credits, in the typical U.S. system. The generally high education level of those who completed the course is discussed later in this paper.

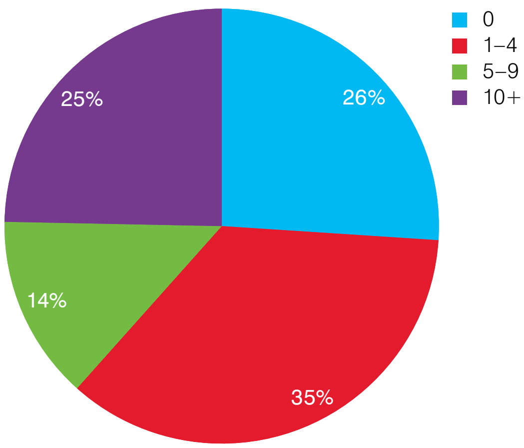

Figure 6. *Number of college science courses previously taken by the sample of 2465 MOOC participants who took the external Science Literacy survey. As many as a quarter were likely to already have a science degree.*

The learners' intentions and motivations were measured through the Coursera entry survey. This instrument has 22 questions, and it starts by asking about the intentions behind watching the video lectures, completing the assessments, participating in the forums, and attaining a completion certificate. It then probes various motivations for taking the course, using a five-point Likert scale with responses ranging from "not at all important" to "absolutely critical." The survey ends with three questions about previous familiarity with the subject matter of the course, and two open-ended questions about why the learners are taking the class. People who completed the entry survey were self-selected to be much more motivated that the typical person who registers for the course. This group of 4969 splits roughly equally into those who did not attempt to complete the course, those who tried to complete the course but failed, and those who passed (Figure 7).

Various levels of intention and commitment were seen at the beginning of the course. About 85% intended to watch all the lectures, 71% intended to do all the assessments, 26% intended to participate in the discussion forums, and 46% intended to achieve a paid completion certificate or a free statement of accomplishment. The people taking this MOOC generally had some prior interest or background in astronomy. Just 10% had actual work experience in astronomy, but a third had taken astronomy coursework, and over 70% said they were somewhat or very familiar with the subject. The survey listed ten reasons for taking the course. The reason where the highest percentage of respondents said it was "very important" or "absolutely critical" (80%) was "for general interest, curiosity, or enjoyment," bolstering the premise that these free-choice learners are not studying astronomy with a practical or a vocational motivation. There was a large drop down to the next set of reasons given by respondents for enrolling in the course: 21% to earn a completion certificate, 10% for gaining skills that might be useful in a new job, 9% for connecting to other students interested in astronomy, 8% to take a course from this particular professor, and 8% to take a course from this particular institution.

Additional clues to learner motivation came from analysis of the open-ended responses to the last two questions in the entry survey: "Why are you taking this class?" and "Do you have any additional comments?". Word counts of the answers to those questions showed the most frequent keyword, by a factor of two, to be "interest." The next most frequently counted keywords were: learn, want, curiosity and knowledge. Curiosity is a central attribute of people who become scientists so it's gratifying that it is also one of the core motivations for people taking this online astronomy course (Figure 8).

In these data, we can see reasons for the typically low completions rates of a MOOC. More than half of those enrolled were between the age of typical students and retirement age. More than half already had a college degree, often a Masters or a Doctorate. More than half were working professionals. People in this segment of the adult population often have busy lives and

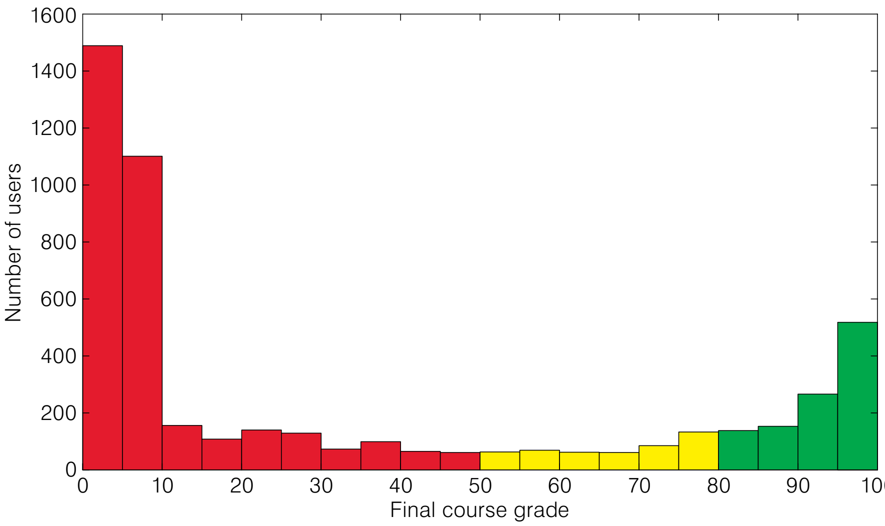

Figure 7. *Grade distribution of the 4969 MOOC participants who completed the Coursera entry survey. Red indicates failing the course, yellow indicates passing, and green indicates passing with distinction.*

Figure 8. *Word cloud from responses to the question "Why are you taking this class?" from the 4657 MOOC participants who took the Coursera entry survey. Size indicates the relative frequency of the word.*

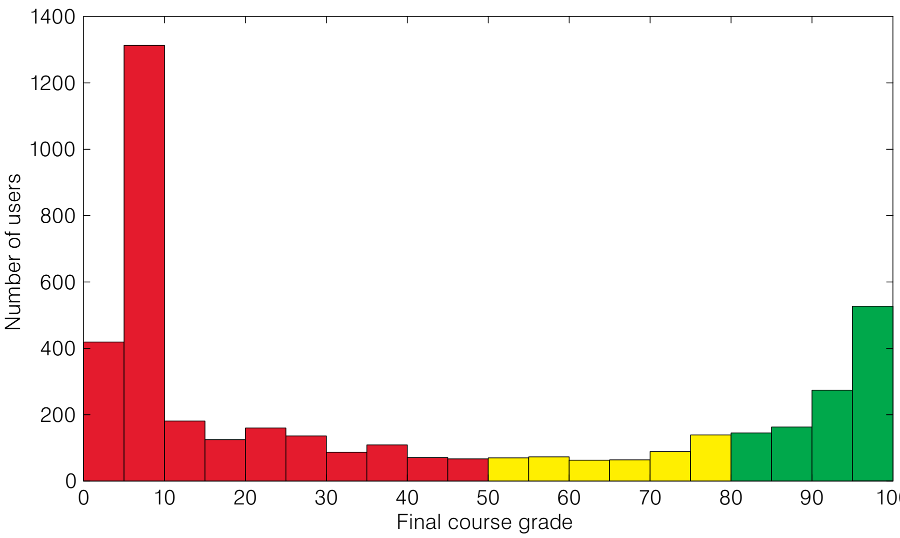

Figure 9. *Grade distribution of the 4275 MOOC participants who did at least one assignment. Red indicates failing the course, yellow indicates passing, and green indicates passing with distinction.*

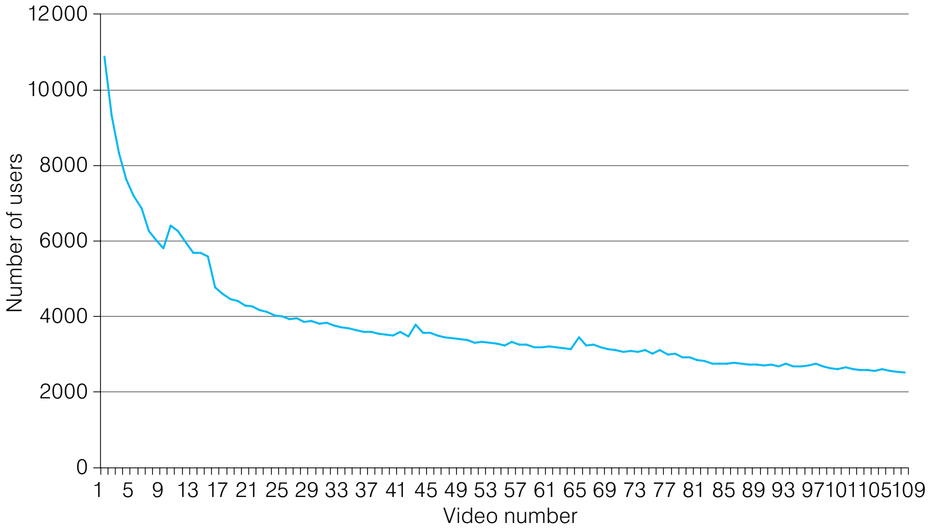

Figure 10. *The number of MOOC participants who watched each of the 109 videos. An exponential decline in the first week was followed by a slower, more linear decline, with slight increases at the start of most modules or major topics.*

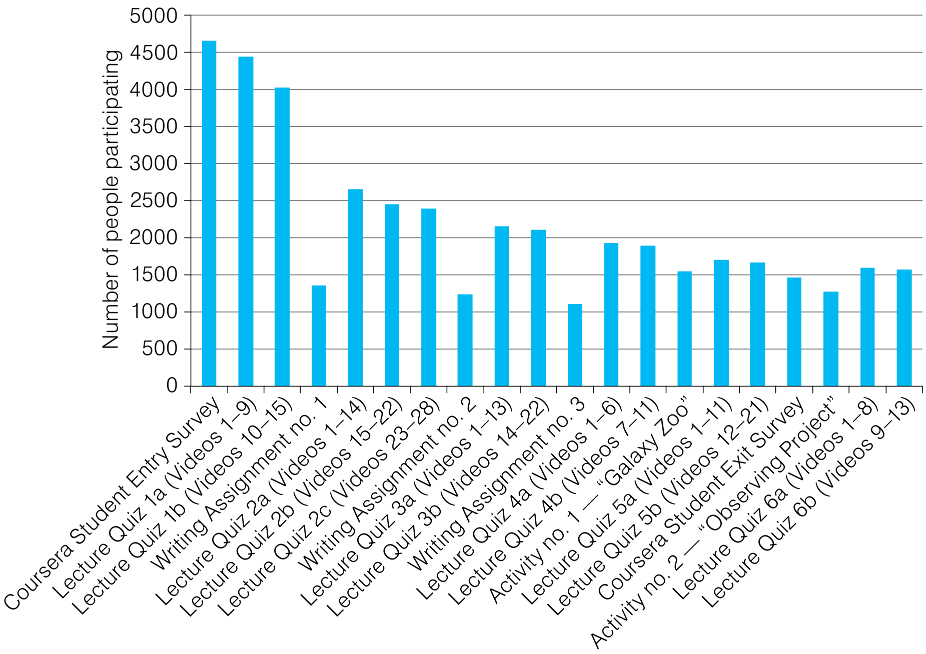

Figure 11. *The number of MOOC participants who completed each of the surveys and graded assignments, showing a sharper drop for each of the writing assignments.*

are juggling family and work. Even though 80% expressed an intention to watch all of the video lectures, and 70% intended to complete all of the assignments, only 1 in 5 of those intending to complete the course actually did so. Therefore, 20% could be viewed as a practical ceiling on the likely completion rate in this type of free-choice, informal learning environment.

Learner engagement and outcomes

Out of 25 379 people registered at the beginning of the course, 21 104 (83%) did not complete any graded assignment. They are referred to as "phantoms" in the online world because they express an initial interest by registering, but are probably browsing or window-shopping with no intention of completing the course. The remaining 4275 learners divide into 1607 who passed by achieving the required minimum of 50% across all of the assignments and 2668 who failed by not scoring at least 50% on the assignments. Of the 1607 who passed the course, 1109 (69%) passed with distinction, a grade of 80% or better, and 498 (31%) passed with a grade between 50% and 80%. The number of people registered and paid for a completion certificate was 296, of which 247 (84%) actually passed the course and so received the certificate from Coursera. The most salient percentages are that 6% of the people who registered passed the course and 69% of those who passed did so with distinction. This suggests a bimodal distribution of performance, with most participants doing a few assignments and then falling away from the class, and a small tail performing at a very high level (Figure 9).

Engagement with the content showed a steep or exponential decline over the first week followed by transition to a steady, linear decline over the rest of the course (Figure 10). There was a small surge at the beginning of the second module on Observing, and two smaller upturns at the beginnings of the modules on the Solar System and Stars. Similar data on the participation in graded assignments shows a similar declining curve, with an added interesting feature: there is a substantial drop for each of the three short writing assignments (Figure 11). Apparently, these learners were more interested in watching videos and in taking video quizzes than in writing about astronomy, even though the writing counted for a significant fraction of the total grade. Participants in the discussion forum were among the most engaged learners in the class, and the numbers of posts and comments and new threads shows no particular trend, except for a strong peak for each new module and less prominent peaks for deadlines of peer grading (Figure 12).

The sample size of $n = 25\ 379$ is large enough to test some potentially interesting correlations. Since the video lectures represented the core of the course, it might be anticipated that the number of video lectures watched would correlate strongly with the final score. It does ($r = 0.67$, $p < 0.001$), but the plot shows wide scatter (Figure 13). If those who did not watch any videos are removed, $n = 12\ 042$, the result is still significant ($r = 0.62$, $p < 0.001$)[8]. The correlation

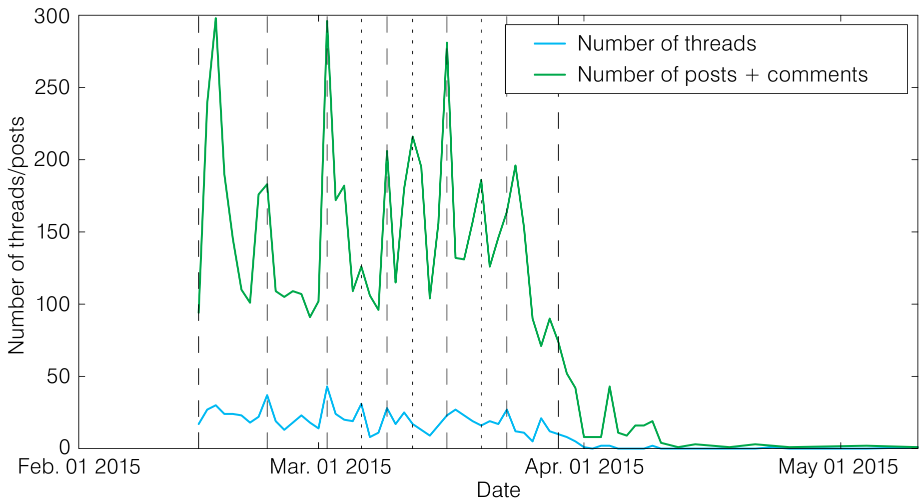

Figure 12. *Activity on the discussion forums for the astronomy MOOC. The number of new threads created is in blue and number of new posts and comments is in green. Most of the peaks correspond to the start of a new module (dashed lines) or the deadlines for peer evaluations of writing assignments (dotted lines).*

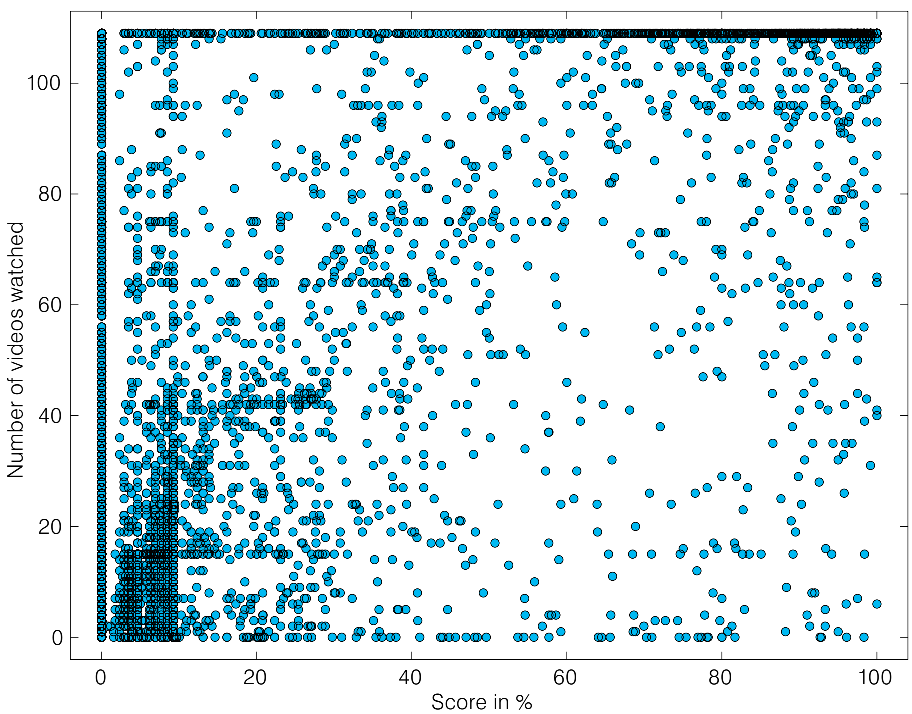

Figure 13. *Final score plotted against number of videos watched by each user (r = 0.67, p < 0.001), with n = 25 379. Despite wide scatter the correlation is significant.*

coefficient is lower because we are removing mostly those who watched no videos and had zero score. On the other hand, if we remove those who did not participate in any assessment, $n = 4275$, the correlation improves ($r = 0.75$ $p < 0.001$). Within the whole population (Figure 13), there are people who failed despite watching all the videos (upper left corner) and there are also people who passed without watching many, or even any, videos (lower right corner). A cohort that is particularly interesting is the vertical slice of those who passed the course with distinction, a score of 80% or better. A group of those high performers cluster at the top, having watched all or nearly all the videos, but below 85 out of 109 videos watched, the distribution is nearly uniform.

For the course participants who had some background in astronomy, or those who were highly motivated to complete all the assignments, video lectures were apparently not essential for success. This has not been noted before and is a particularly surprising result of our study. On the other hand, people watching at least one video watched on average 5.5 hours of content. The distribution is bimodal (Figure 14), and it mirrors the distribution of overall grades (Figure 9). A major goal of MOOCs is outreach rather than formal education, so it is worth noting that, in the aggregate, several thousand people watched 65 200 hours, equating to seven and a half years worth, of astronomy videos as a result of taking this course.

The other type of activity that indicates engagement but is not formally part of the grade was participation in the discussion forums. In this MOOC, forums were the best and often the only form of asynchronous interaction between students and the instructor and his team. We have gathered a wealth of detailed data from the forums, but only summarise the broad results here. The topics of online discussion parse into several categories: comments on specific course content (which is very useful because it includes many eyes catching occasional misstatements in the videos and errors in the assignments); topical threads on recent discoveries and news stories in astronomy; discussion of the practical aspects of amateur astronomy such as where to buy a small telescope and what to observe in the night sky; and threads on potentially controversial issues like science and religion and UFOs. Postings were generally civil and courteous, with only a couple of instances of bad behavior and "trolling," out of nearly 750 people who posted. Overall, people who participated in the forums earned grades twice as high as those who never participated (65% with a standard deviation of 38% versus 32% with a standard deviation of 34%). The difference in these distributions is significant with $p < 0.001$ using a Kolmogorov–Smirnov test[9]. The number of posts also correlates weakly with grade for the whole population, $n = 25\,379$ ($r = 0.16$, $p < 0.001$) and this result weakens even more if people who did not participate in the forums are excluded, $n = 749$ ($r = 0.11$, $p = 0.003$).

The strongly positive responses in the exit survey naturally reflect the views of those

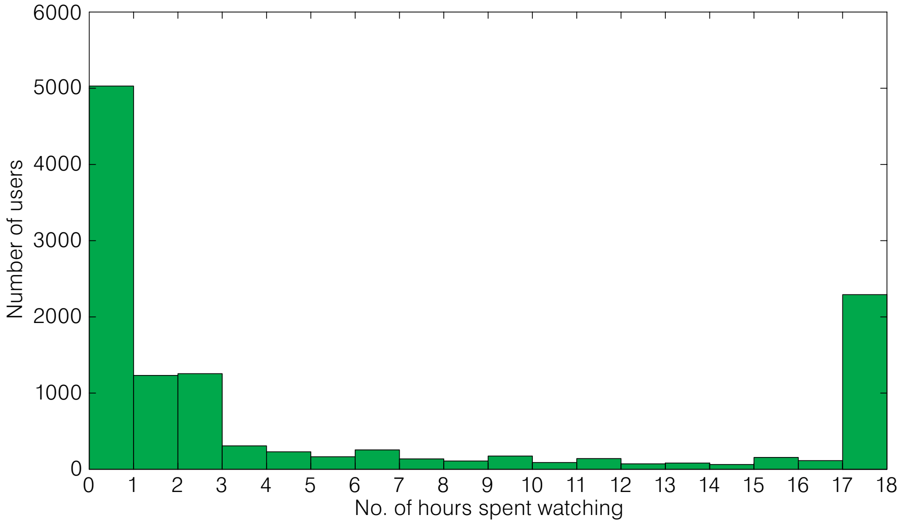

Figure 14. *Bimodal distribution of number of hours of video watched by the MOOC participants, mirroring Figure 7, with n = 12 042. The median amount watched was 5.5 hours for those who watched at least one video.*

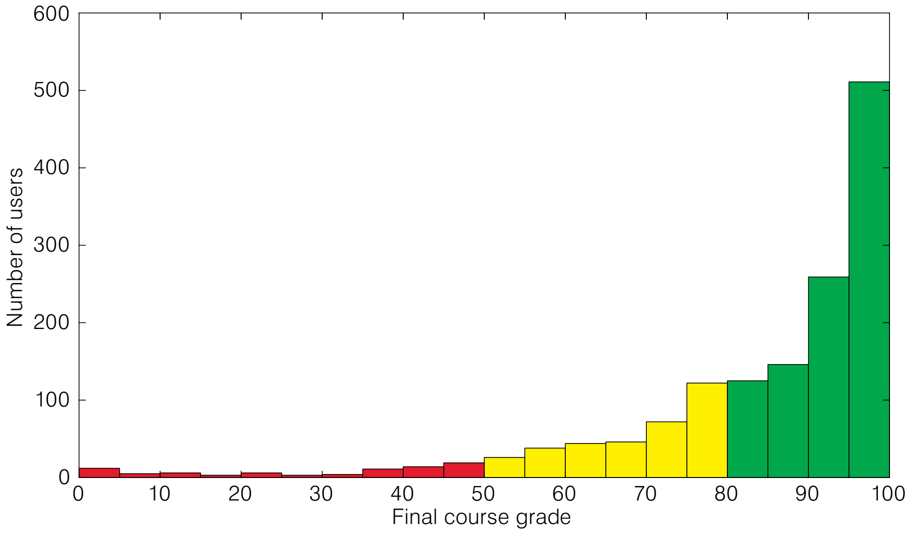

Figure 15. *Grade distribution for MOOC participants who completed the exit survey (n = 1472). It is strongly skewed towards people who performed well in the course.*

who performed particularly well in the course (Figure 15). The learner experience was measured by Coursera using their standard exit survey, taken by an anonymous subset of 1472 of those enrolled who also finished the class. On the overall experience, 52% rated it excellent, 34% rated it very good, 12% rated it good, and only 2% rated it fair or poor. In general, learners thought the level of difficulty was slightly easier than expected, workload was slightly heavier than expected, and the pace slightly faster than expected. In terms of their satisfaction with various components of the course, the judgement was the most positive for instructor knowledgeability (96% very good or excellent), instructor clarity (91% very good or excellent), and the videos (87% very good or excellent), and lower for assessments (63% very good or excellent) and the discussion forums (37% very good or excellent). In terms of potential changes and improvements, the most popular suggestion was to spread the content over more than six weeks (53% positive), along with covering more topics (52% positive). Survey respondents were more tepid on the idea of splitting the course into multiple, shorter courses (31% positive). Only one in four said they would have taken this course if it had not been free.

The exit survey also asked how well the course met the goals and expectations of the learners. Overall satisfaction was high. Over 90% strongly agreed or somewhat agreed that their goals in taking the course were met. The motivations were recreational rather than vocational; only 24% said that the topic of the course was relevant to their current or potential career.

People were asked how the course affected their understanding of astronomy. The percentage with excellent understanding increased from 3% to 18%, and the percentage with very good understanding increased from 12% to 53%. The primary goal of any course is increasing content knowledge, so it is a solid success when the percentage of learners with very good or better understanding grows from 15% to 71%. Consistent with the premise of lifelong learning, 85% said they would be likely to revisit the class materials and 41% even said they would be likely to take the class again. Additionally, 92% said they would be likely to recommend the course to a friend and 90% said they would take another course by the same instructor.

What are the particular characteristics of those who completed the course?

We were able to study characteristics of those who completed the course using data from our external survey of 2465 participants. The percentage of learners who completed the course rises with age, peaking at 46% with the cohort who were in their fifties, dropping slightly for the oldest group (Figure 16). Not surprisingly, completion rate rises with education level, from 26–28% for those with no college education, to nearly 50% for those with a doctorate (Figure 17). By comparing age distribution from Figure 2, educational distribution from Figure 4 and distribution of previous college science courses from Figure 6 with the same distributions for the course graduates we conclude that they are significantly statistically different populations, with $p < 0.05$ determined by a Kolmogorov–Smirnov test. Therefore, we can state that graduates were typically older and more educated than the general survey population. The highest performing learners were retirees, who had over 40% completion. At slightly lower levels of performance were people in technical fields or professional jobs. Unemployed people were in the middle of the distribution,

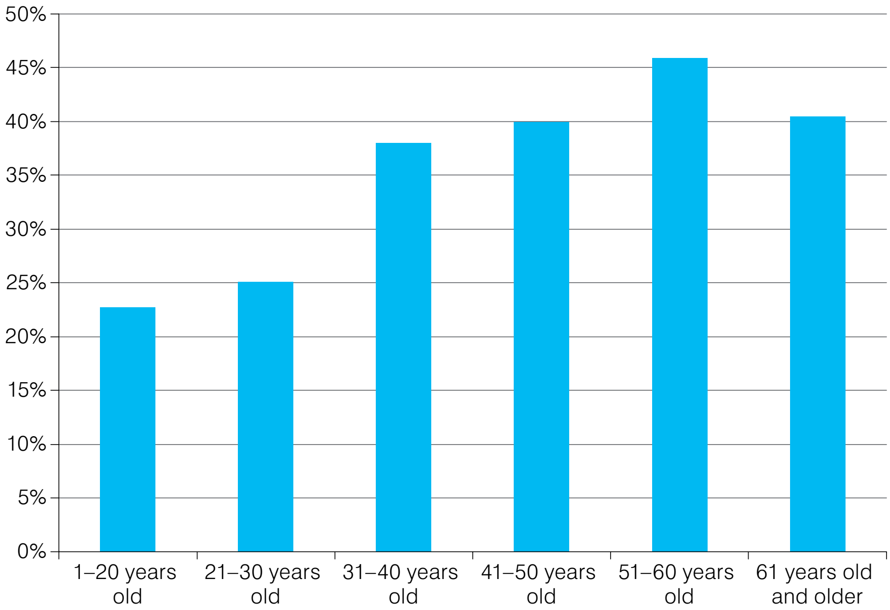

Figure 16. *Percentages of graduates in each age category, based on demographics data from the Science Literacy survey.*

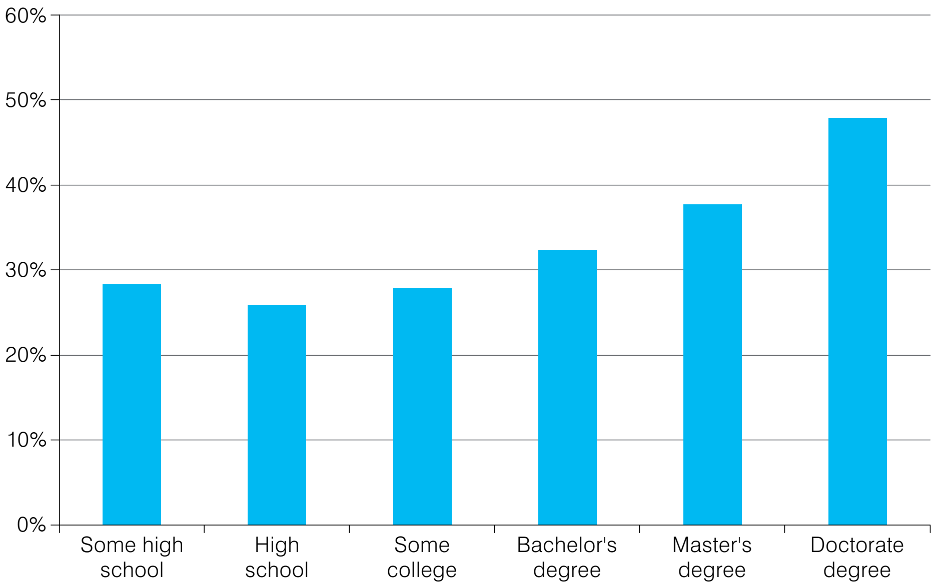

Figure 17. *Percentages of graduates for groups with different educational background based on demographics data from the Science Literacy survey.*

at 33%, and students performed poorest of all major categories, with 25% completion (Figure 18). The different motivations of this diverse population cannot be neatly summarised, but taking an online course with eighteen hours of video content and two dozen assignments is time-consuming, so it is not very surprising that the retired population did much better than average in this course.

What are the major predictors of completion, especially early in a course like this?

The baseline for this discussion should omit the "phantoms" who never opened the course or completed any assignment. That baseline is the 11% of people who opened the course and then completed the course and graduated. Participation of any kind boosts the odds of completion, but there are different levels of predictors. In the lowest tier, 33% of those who did the science literacy survey at the beginning of the course completed the course and 36% of the people who did the first video quiz completed the course. In the middle tier, there was a 67% completion rate for people who participated, even just once, in the discussion forums. In the highest tier as far as percentage who graduated are: 81% of those who did the first writing assignment; 83% of those who chose the certificate path; 89% of those who did required peer reviews for the first writing assignment; and 94% of those who did the first activity (Figure 19). The message to be drawn from this data is that early engagement in the more intensive assessments like writing and projects is a strong predictor of success in this MOOC.

Summary and future research

Massive open online classes are still in their early days of development, so their full impact on education is not yet clear. However, the potential of MOOCs to facilitate free-choice learning and outreach is beyond doubt. Material that was once confined to enrolled students at major universities is now available free of charge online. MOOCs have gained enormous geographic reach from the penetration and diminishing cost of Internet access across the world.

Astronomy: Exploring Time and Space has put the cutting edge research results of astronomy in the hands of thousands of people in over 150 countries. Even though 41% of those who registered for the course did not "open" the course, the 12 042 people who did watched 65 200 hours of astronomy lectures on video. These participants were generally older than 30 years, and had some level of college education, but their jobs and work experiences were varied. A course like this can meet the goals of lifelong learners to increase their understanding of a technical subject for the purest of motivations: curiosity and intellectual enjoyment (Koller et al., 2013). More nuanced measures of success than completion rate are needed to fairly evaluate MOOCs (Klobas, 2014).

MOOCs give learners great flexibility in being able to access instructional materials anytime and in any place (the Coursera platform delivers materials to handheld devices), and free access means they

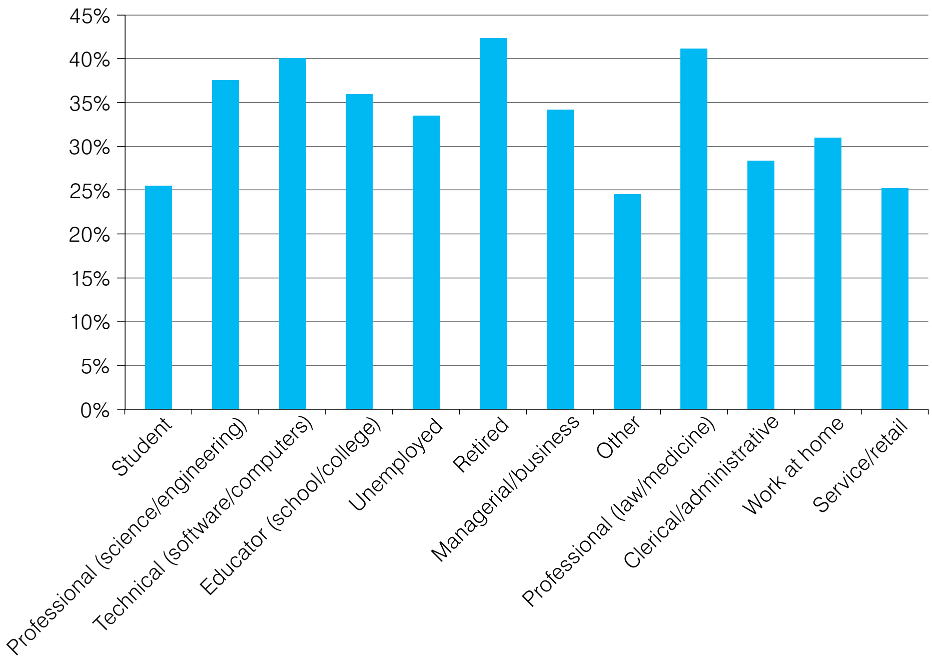

Figure 18. *Percentages of graduates for different occupations, based on the external Science Literacy survey.*

really are available to anyone. On the other hand, without the financial commitment of tuition, and the incentive of a grade and college credit, learners are far less invested in the experience than the typical college student. As a result, the completion rate is low. Like other MOOCs, we saw a steep decline in participation and engagement with time over a 6-week course. Out of more than 25 000 registered at the start of the course, only 17% completed any graded assignment. Among those 4275, 38% completed the course with a passing grade of over 50%. Two thirds of those who passed did so with distinction, a grade of over 80%. Performance and participation was bimodal, with a small tail of very engaged and highly achieving students. Those who completed the course were older and more educated than the average participant and they tended to be either students, professionals working in sciences, or educators. The strongest predictors of completion were participation in early assessments like the peer writing and the project, and participation in the discussion forums (Jiang, 2014). Going beyond multiple choice tests and simple forms of assessment to add more interesting and challenging projects may help reduce class attrition (Gutl et al., 2014). The variables that affect student success in MOOCs are still being actively investigated (Reich, 2015; Reilly, 2013).

We plan to continue exploring pedagogy that increases engagement in MOOCs and improves the completion statistics. To do this will require more evaluation of written work, using peer grading since that is the only way to handle thousands of assignments. We will also explore ways to do project-based or hands-on science online, in particular with the type of Citizen Science tool that we used in this course: the galaxy classification activity called Galaxy Zoo. Another approach we will explore is to try and replicate the learning potential of face-to-face group activities like lecture tutorials in an online environment. We will also continue using surveys to better understand the level of incoming science literacy of the learners and their motivation for taking a MOOC. In 2015, we transitioned *Astronomy: Exploring Time and Space* to Coursera's on-demand platform, where people can enrol continuously and finish the class at their own pace. This platform is well-suited to trying out new approaches in successive versions of the class, and tracking the outcomes for each cohort. As research on MOOCs grows, and best practices spread, we expect them to become increasingly important for formal, distributed learning.

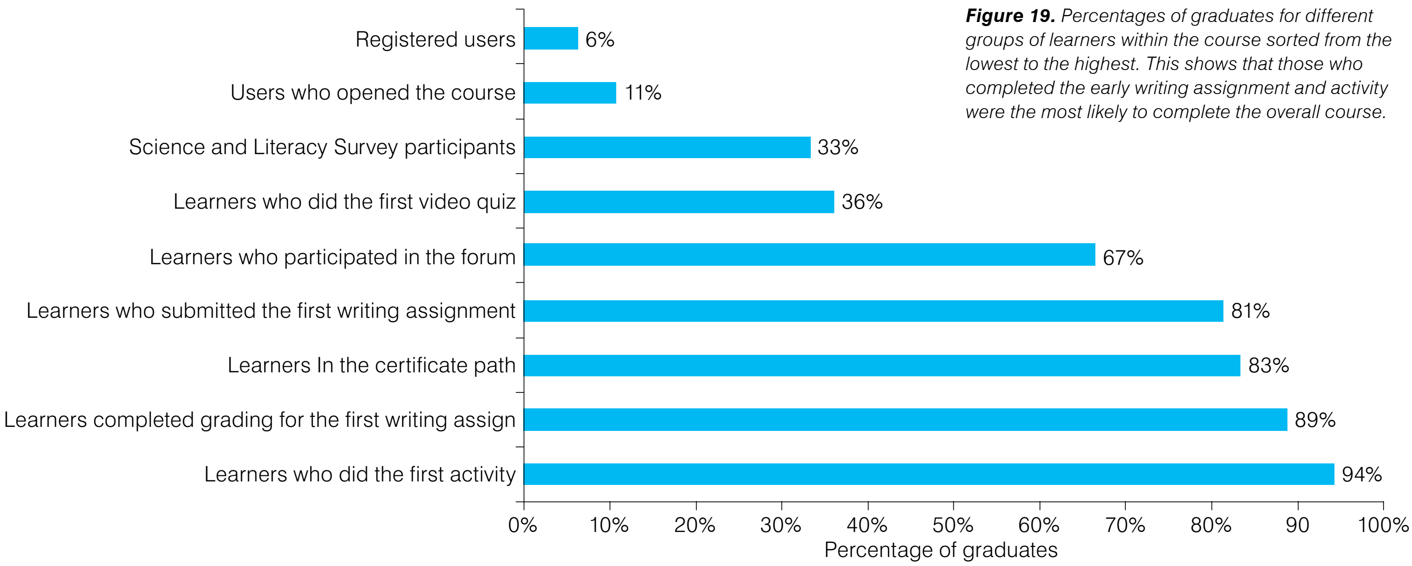

Figure 19. *Percentages of graduates for different groups of learners within the course sorted from the lowest to the highest. This shows that those who completed the early writing assignment and activity were the most likely to complete the overall course.*

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Notes

1. Coursera: https://www.coursera.org
2. edx: https://www.edx.org/
3. Udemy: https://www.udemy.com/
4. Final Cut Pro X: http://www.apple.com/final-cut-pro/
5. Teach Astronomy: http://www.teachastronomy.com
6. Sloan Digital Sky Survey: http://www.sdss.org/
7. MicroObservatory Robotic Telescope Network: http://mo-www.harvard.edu/OWN/
8. r here is the correlation coefficient whilst the calculated probability is denoted with the p-value
9. More information on the Kolmogorov–Smirnov test: https://en.wikipedia.org/wiki/Kolmogorov–Smirnov_test

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Biographies

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